

# Analysis of Business Models for EV Fleets in Cities

**Memory**

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## Review

This thesis examines the transition from internal combustion engine (ICE) fleets to electric vehicle (EV) fleets. In particular, there is a focus on the economic effects from the point of view of the fleet owner, as well as overall environmental effects.

This is accomplished through case studies involving different fleet-based business models and analysing the resulting effects of a transition to EV fleets. Furthermore, comparisons will be made between similar scenarios in two different European cities, namely Barcelona and Stockholm. Additionally, aid and incentives to motivate a change from ICE and EV fleets are explored in detail.

The results show annual savings of 4,279.94 EUR/year and 6,352.33 EUR/year for taxi drivers in Barcelona and Stockholm respectively, and 6,405,121 EUR/year and 8,594,734 EUR/year for public bus operators in Barcelona and Stockholm respectively.

Furthermore, the results show a reduction in local emissions of 12,727 kg CO<sub>2</sub>/year for taxi drivers in Barcelona and Stockholm, and 22,835,163 kg CO<sub>2</sub>/year and 19,134,464 kg CO<sub>2</sub>/year for public bus operators in Barcelona and Stockholm respectively.

Finally, savings for delivery service fleets are shown to range from 18.25 EUR for 4,000 km up to 3,744.25 EUR for 50,000 km.

The thesis concludes by acknowledging the large positive environmental effects, while also pointing out that despite the yearly economic savings, there is still a large financial burden associated with a transition to EV fleets. Ways in which this financial burden can be reduced include increasing the annual kilometres driven by vehicles in the fleet, and increasing the difference in cost between electricity and fuel prices.



# Summary

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# 1. Introduction

The intention of this thesis is to explore the motivations for, and results from, a transition between traditional internal combustion engine (ICE) fleets and electric vehicle (EV) fleets. We will consider these aspects from the point of view of both public and private fleet owners. The report will examine challenges associated with the transition and widespread adoption of electric vehicle fleets, the motivations for this transition, and the incentives for doing so.

Among the associated issues, the economic effects of this transition for the fleet owner, as well as the financial burden will be examined and quantified. In addition, the environmental effects of the transition will be examined and quantified.

This will require background on and thorough understanding of electric vehicles, which will be covered first.

## 1.1. Objectives of the Thesis

The objectives of the report are as follows:

- Create a thorough understanding of electric vehicles from a technical, infrastructural, environmental, and regulatory view as a basis for deeper insights into electric vehicle fleets
- Explore the existing status of electric vehicle fleets
- Explore the incentives and motivations influencing a transition to electric vehicle fleets
- Examine and quantify the economic and financial aspects of a transition to electric vehicle fleets
- Examine and quantify the environmental aspects of a transition to electric vehicle fleets

## 1.2. Scope of the Thesis

The focus with of the thesis will be on electric vehicle fleets, both public and private, as opposed to private owners. The thesis will be Europe-focused, with an emphasis on Barcelona and Stockholm.



## **2. Background on Electric Vehicles**

### **2.1. Electric Vehicle Basics**

At its most basic, an electric vehicle is any road vehicle which involves electric propulsion. Although first invented in 1834, the development and advancement of internal combustion engine based vehicles resulted in the disappearance of electric vehicles in the scene since 1930. In the 1970s, however, concern over the energy crisis lead to renewed interest in electric vehicles. Over the last few decades, environmental issues and the rising price of oil have become even stronger driving forces for the development and deployment of electrical vehicles. Today, many regulatory initiatives continue to help contribute to the increase of electric vehicle adoption worldwide [1].

### **2.2. Types of Electric Vehicles**

There are four major types of electric vehicles: Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Fuel Cell Electric Vehicles (FCEVs). In this section, we will briefly give an overview of each type and discuss its relevance with respect to the overall topic.

#### **2.2.1. Battery Electric Vehicles (BEVs)**

Battery Electric Vehicles are defined as vehicles which are purely powered by batteries and propelled by an electric motor. BEVs draw power from the electric grid and therefore have zero local emissions (exhaust). The major drawbacks of BEVs are the generally high initial cost, limited driving range, and reliance on fast charging infrastructure, which does not exist in many places. For these types of vehicles to continue to be viable in the future, we will need to see breakthroughs in battery technology to increase the driving range, cycle life, and cost per kilowatt-hour (kWh) [2].

#### **2.2.2. Hybrid Electric Vehicles (HEVs)**

Hybrid Electric Vehicles are defined as vehicles that are powered by both batteries and liquid fuel (i.e. gas or diesel) and propelled by an electric motor and a traditional internal combustion engine. In HEVs, electric power is generated by the built-in internal combustion engine or by

recovering energy from the braking system, which is then used to recharge the battery. This second method is called regenerative braking, whereby kinetic energy is converted into chemical energy to be stored in the battery. These types of vehicles do not accept charge from any external energy sources, such as the power grid [2].

### **2.2.3. Plug-in Hybrid Electric Vehicles (PHEVs)**

Plug-in Hybrid Electric Vehicles differ from HEVs in that they can charge the battery by the methods used by HEVs, but also by plugging into the electrical grid. Due to this feature, PHEVs have larger battery packs and can propel the vehicle in an all-electric drive mode for longer than a HEV. The PHEV can operate in two modes: charge depleting mode and charge sustaining mode. Generally, the vehicle will operate in charge depleting mode at start up, where the propulsion power comes from the battery. When the state of charge reaches a certain threshold, charge sustaining mode is switched on. In this mode, the internal combustion engine turns on and contributes to powering the vehicle [2].

### **2.2.4. Fuel Cell Electric Vehicles (FCEVs)**

Fuel Cell Electric Vehicles are defined as vehicles which use fuel cells along with batteries as an energy source. Like BEVs, these vehicles produce zero local emission (exhaust). They have an advantage of a driving range similar to that of internal combustion engine vehicles. This technology, however, is still very much in a developmental stage. Furthermore, there is a lack of hydrogen refuelling infrastructure at the present time [3].

### **2.2.5. Summary**

Figure 1 on the following page shows a summary of the different electric vehicle types. It provides an overview of the different propulsion and energy systems, energy sources, characteristics, and major issues with each electric vehicle type.

Types of EVs	Battery EVs	Hybrid EVs	Fuel Cell EVs
Propulsion	<ul style="list-style-type: none"> <li>• Electric motor drives</li> </ul>	<ul style="list-style-type: none"> <li>• Electric motor drives</li> <li>• Internal combustion engines</li> </ul>	<ul style="list-style-type: none"> <li>• Electric motor drives</li> </ul>
Energy system	<ul style="list-style-type: none"> <li>• Battery</li> <li>• Ultracapacitor</li> </ul>	<ul style="list-style-type: none"> <li>• Battery</li> <li>• Ultracapacitor</li> <li>• ICE generating unit</li> </ul>	<ul style="list-style-type: none"> <li>• Fuel cells</li> </ul>
Energy source & infrastructure	<ul style="list-style-type: none"> <li>• Electric grid charging facilities</li> </ul>	<ul style="list-style-type: none"> <li>• Gasoline stations</li> <li>• Electric grid charging facilities (optional)</li> </ul>	<ul style="list-style-type: none"> <li>• Hydrogen</li> <li>• Methanol or gasoline</li> <li>• Ethanol</li> </ul>
Characteristics	<ul style="list-style-type: none"> <li>• Zero emission</li> <li>• Independence on crude oils</li> <li>• 100-200 km short range</li> <li>• High initial cost</li> <li>• Commercially available</li> </ul>	<ul style="list-style-type: none"> <li>• Very low emission</li> <li>• Long driving range</li> <li>• Dependence on crude oils</li> <li>• Complex</li> <li>• Commercially available</li> </ul>	<ul style="list-style-type: none"> <li>• Zero emission or ultra low emission</li> <li>• High energy efficiency</li> <li>• Independence on crude oils</li> <li>• Satisfied driving range</li> <li>• High cost now</li> <li>• Under development</li> </ul>
Major issues	<ul style="list-style-type: none"> <li>• Battery and battery management</li> <li>• High performance propulsion</li> <li>• Charging facilities</li> </ul>	<ul style="list-style-type: none"> <li>• Managing multiple energy sources</li> <li>• Dependent on driving cycle</li> <li>• Battery sizing and management</li> </ul>	<ul style="list-style-type: none"> <li>• Fuel cell cost</li> <li>• Fuel processor</li> <li>• Fueling system</li> </ul>

Figure 1 - Overview of EV Types [1]

## 2.3. BEV Topology

In a BEV, the electric motor is used as the only propulsion source. As such, the propulsion system is all electric and will always operate in charge depleting mode. Large battery packs integrated into the vehicle will be recharged by regenerative braking during use and charged via the electrical grid when the vehicle is not in use. The downside to this is that BEVs are limited in the distance they can travel based on the capacity of the battery. Due to this, BEVs are best suited for city driving [2]. See Figure 2 below for a typical BEV topology.

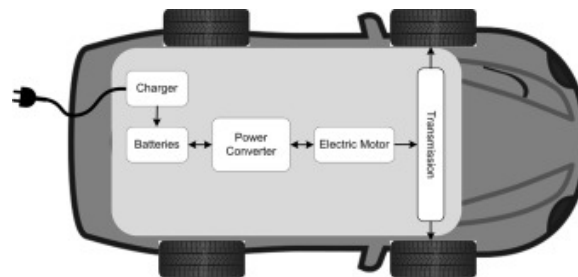


Figure 2 - BEV Topology [2]

## 2.4. HEV and PHEV Topologies

Both HEVs and PHEVs are propelled using two energy sources, namely the electric motor and internal combustion engine. Several power train topologies have been developed, each with their own set of objectives such as improving fuel economy, increasing power, or minimizing cost. The most common topologies are series, parallel, and series-parallel, as shown in Figure 3 [2].

### 2.4.1. Series Topology

A series topology uses electric motor power as the only source of propulsion. The internal combustion engine and generator are used to recharge the battery, along with regenerative braking, when the state of charge of the battery becomes low. The internal combustion engine is decoupled from the transmission and wheels, while the electric motor is mechanically attached to the transmission and wheels. This topology is best suited for urban driving as it can deal with a start/stop driving pattern well [2].

### 2.4.2. Parallel Topology

In contrast with the series topology, a parallel HEV or PHEV has both the internal combustion engine and the electric motor mechanically coupled to the transmission. Both machines simultaneously transmit power to the wheels to propel the vehicle. Since two propulsion sources are used in this topology, the overall efficiency of the vehicle is higher than the series topology, and is approximately 40% more efficient than a conventional vehicle. Parallel topology vehicles are suitable for both urban and highway driving. This is because both the electric motor and internal combustion engine can complement each other during the various driving conditions [2].

### 2.4.3. Series-Parallel Topology

The series-parallel topology combines features from both series and parallel. Like the parallel topology, both the internal combustion engine and electric motor are mechanically coupled to the transmission and wheels. This topology has the ability to run in either series or parallel mode. Despite having advantages of both series and parallel topologies, this series-parallel topology suffers from being complex and costly [2].

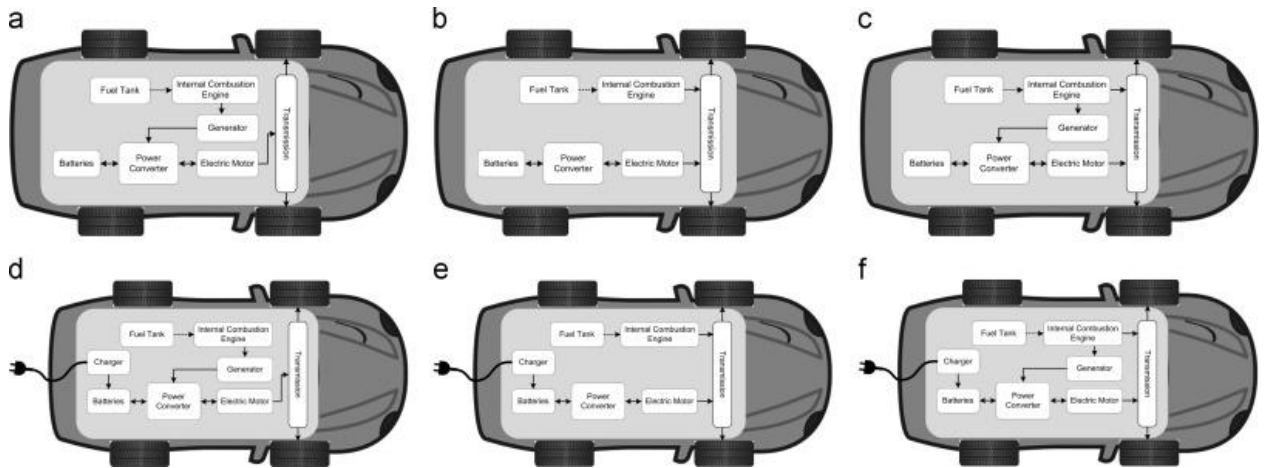


Figure 3 - Power train configurations: (a) Series HEV, (b) Parallel HEV, (c) Series-parallel HEV, (d) Series PHEV, (e) Parallel PHEV, (f) Series-parallel PHEV [2]

## 2.5. Electric Vehicle Battery Types

Batteries are one of the most important component in an electric vehicle system. It is the only source of propulsion for BEVs and one of the two sources of propulsion for HEVs and PHEVs. Electric vehicle batteries are currently the biggest barrier for wider adoption of these types of vehicles. Since current electric vehicle batteries have a relatively low energy density, the range of the vehicle is limited. Fortunately, there have been a number of breakthroughs in battery technology over the past several years. Figure 4 below shows the timeline of EV battery development. Next, we will discuss the different types of electric vehicle batteries.

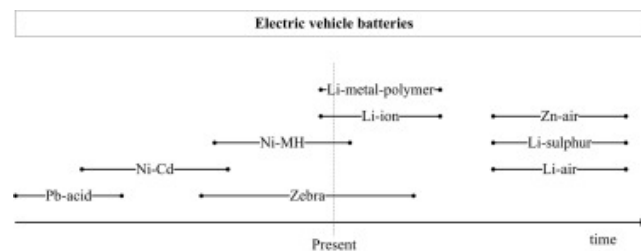


Figure 4 - Timeline of EV Batteries [2]

### **2.5.1. Lead Acid (Pb-Acid)**

These are the oldest type of batteries that are used worldwide. Some major disadvantages of these types of batteries are the issues with handling acid substances, the use of toxic lead in the construction, a relatively low stored energy versus weight ratio, and a relatively low stored energy versus volume ratio. Due to the inexpensive manufacturing technology and the relatively high ratio of electric power versus weight they are an inexpensive solution for use in electric vehicles [4].

### **2.5.2. Nickel-Cadmium (NiCd)**

Compared with all the other batteries, nickel-cadmium have the longest lifespan in terms of charge and discharge cycles (approximately 1500 cycles). The major disadvantage of these types of batteries is the utilization of a heavy metal (cadmium) in its construction, which has the potential for harmful effects on the environment and health. As such, the EU has directives to limit the use of these types of battery [4].

### **2.5.3. Nickel-Metal-Hydride (NiMH)**

The operation and manufacturing technology for this type of battery is similar to that of the NiCd battery. The major benefit of these batteries is a lack of memory effect, which will influence the maximum load capacity of the battery. When comparing with Li-ion batteries, the batteries of this type have a lower capacity for energy storage as well as a higher coefficient of self-discharging [4].

### **2.5.4. Lithium-Ion (Li-Ion)**

A large capacity for power storage and a very good energy density versus weight ratio characterizes this battery type. Its widespread adoption is limited by a few major issues. These include high costs, an overheating potential, and a limited life cycle, although it is better in many ways than the NiMH battery [4].

### **2.5.5. Lithium-Ion Polymer**

These batteries provide a greater life cycle than the classic Li-ion batteries. However, they present a functional instability in the case of an overload and in the case of discharges of the battery below a certain value [4].



### 2.5.6. Sodium Nickel Chloride (NaNiCl)

These batteries are sometimes known as “zebra batteries”. They use a molten salt electrolyte which has an operating temperature of 270–350 °C. It has the major advantage of having a very high stored energy density. However, it has major disadvantages due to issues with operational safety and storage for longer periods of time [4].

### 2.5.7. Summary

As you can see, each battery has its own set of advantages and disadvantages when used for electric vehicle system applications. Some of the major points are summed up in Figure 5 and Figure 6 below.

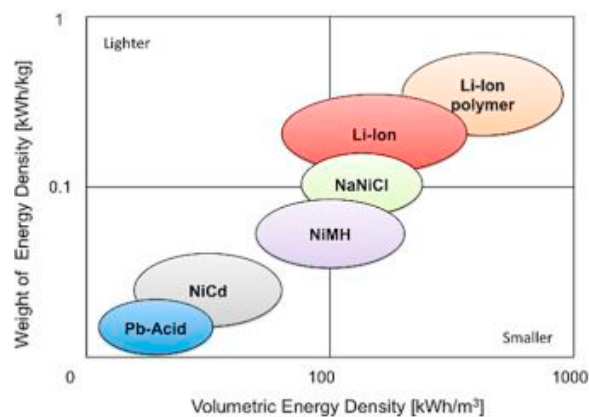


Figure 5 - Comparison of Battery Energy Densities [4]

Battery type	Nominal voltage (V)	Energy density (Wh/kg)	Volumetric energy density (Wh/L)	Specific power (W/kg)	Life cycle	Self discharge (% per month)	Memory effect	Operating temperature (°C)	Production cost (\$/kWh)
Lead acid (Pb-acid)	2.0	35	100	180	1000	< 5	No	-15 to +50	60
Nickel-cadmium (Ni-Cd)	1.2	50–80	300	200	2000	10	Yes	-20 to +50	250–300
Nickel-metal hydride (Ni-MH)	1.2	70–95	180–220	200–300	< 3000	20	Rarely	-20 to +60	200–250
ZEBRA	2.6	90–120	160	155	> 1200	< 5	No	+245 to +350	230–345
Lithium-ion (Li-ion)	3.6	118–250	200–400	200–430	2000	< 5	No	-20 to +60	150
Lithium-ion polymer (LiPo)	3.7	130–225	200–250	260–450	> 1200	< 5	No	-20 to +60	150
Lithium-iron phosphate (LiFePO <sub>4</sub> )	3.2	120	220	2000–4500	> 2000	< 5	No	-45 to +70	350
Zinc-air (Zn-air)	1.65	460	1400	80–140	200	< 5	No	-10 to +55	90–120
Lithium-sulfur (Li-S)	2.5	350–650	350	–	300	8–15	No	-60 to +60	100–150
Lithium-air (Li-air)	2.9	1300–2000	1520–2000	–	100	< 5	No	-10 to +70	–

Figure 6 - Comparison of EV Battery Types [2]

## **2.6. Charging Infrastructure for Electric Vehicles**

### **2.6.1. Introduction**

Needless to say, charging is an extremely important consideration for electric vehicles. This section aims to give an overview of the different charging standards and technology. Battery chargers for electric vehicles can be classified in a number of ways: on-board or off-board, and with bidirectional or unidirectional flow. Unidirectional charging is simpler and therefore a sensible first choice, as it limits hardware requirements, makes interconnection issues simpler, and generally tends to reduce the degradation of batteries. Bidirectional charging systems allow for not only charging from the grid to battery, but also for the injection of energy back into the grid from the battery. It also allows for power stabilization with adequate power conversion. On-board chargers will typically limit higher powers due to weight, space, and cost constraints. However, these problems can be avoided by the integration into an electric drive. On-board charging systems can be designed as either inductive, or conductive. An inductive charging system uses magnetic power transfer. A conductive charging system has a direct contact between the charge inlet and the connector. Off-board battery chargers can generally be used for higher powers since they are not so much constrained by weight and size.

Charger power levels are an important consideration, as they will reflect the charging time, power, location, cost, equipment, and effect on the grid. These next sections will describe the three different levels of charging [5].

### **2.6.2. Power Level One**

This method of charging is the slowest. In USA, this level will use a standard single phase grounded outlet at 120 volts / 15 amps. This is generally for home or business locations, as it does not require additional infrastructure. This level can be useful for a customer for overnight charging, as lower off-peak rates are often available in the evening. An estimate for the installed cost of a level one charger is reported at about 500 – 880 USD. That said, it is a general expectation that this would be already integrated into the vehicle [5].

### **2.6.3. Power Level Two**

This level of charging is the major charging method for dedicated public and private charging facilities. Much of the infrastructure could be found on-board as to avoid redundancies in the

power electronics. Currently, this level of charging equipment is available between 208 and 240 volts, at up to 80 amps and 19.2 kilowatts. In some cases, it is required to have dedicated equipment and connection installation for public or home units. However, some commercial vehicles such as the Tesla already have the power electronics on board, and therefore only need the outlet. Many homes in the USA have the availability of 240-volt service. The major benefit is that this level is generally capable of charging a typical electric vehicle battery overnight. This fast charging time and standardization of connection are among the reasons that level 2 charging is preferred. Often a separate billing meter is included. A typical installed cost for this level of charger is between 1000 and 3000 USD. Figure 7 shows the new standard connection, with an AC connector on top and a DC connector on the bottom. This is intended to allow either AC or DC fast charging with only one connection necessary [5].

#### **2.6.4. Power Level Three**

This level is for commercial fast charging infrastructure, in which it is possible to charge an electric vehicle battery in one hour or less. The typical use of this would be to install at city refuelling spots and highway rest areas, similar in concept to a gas station. These will often operate using a 480 volt (or even higher) three phase circuit. These would require an off-board charger to provide the necessary regulated AC-DC conversion, however the vehicle connection could be direct DC. This type of charging is not often possible in residential sectors. The cost of installing this level of charger can often be prohibitive, with costs ranging between 30,000 and 160,000 USD. Beyond this cost, the cost of maintenance of such a station must be taken into consideration when looking at this level of charger [5].



*Figure 7 - Level 2 Charging Connection [5]*

### 2.6.5. Summary

Each power level has a specified use, especially with regards to charge time and location of the charger. This information is summarized in Figure 8 below.

Power Level Types	Charger Location	Typical Use	Energy Supply Interface	Expected Power Level	Charging Time	Vehicle Technology
Level 1 (Opportunity) 120 Vac (US) 230 Vac (EU)	On-board 1-phase	Charging at home or office	Convenience outlet	1.4kW (12A) 1.9kW (20A)	4–11 hours 11–36 hours	PHEVs (5-15kWh) EVs (16-50kWh)
Level 2 (Primary) 240 Vac (US) 400 Vac (EU)	On-board 1- or 3- phase	Charging at private or public outlets	Dedicated EVSE	4kW (17A) 8kW (32 A) 19.2kW (80A)	1–4 hours 2–6 hours 2–3 hours	PHEVs (5-15 kWh) EVs (16-30kWh) EVs (3-50kWh)
Level 3 (Fast) (208-600 Vac or Vdc)	Off-board 3-phase	Commercial, analogous to a filling station	Dedicated EVSE	50kW 100kW	0.4–1 hour 0.2–0.5 hour	EVs (20-50kWh)

*Figure 8 - Summary of Charging Levels [5]*

## 2.7. Vehicle to Grid Applications

An exciting potential use for electric vehicles beyond transportation is in vehicle to grid applications. Rather than just being simple consumers of electric energy, electric vehicles have the potential to provide valuable services to the electrical grid. Most importantly, electric vehicles could be used as a method to balance the intermittency of renewable energy sources, such as wind power. The reason this is possible is because electric vehicles can take in energy during periods of low demand (and cost) and then feed it back into the grid during periods of high demand or inadequate energy generation. Essentially, we can think of electric vehicle fleets as enormous energy storage battery banks [6].

This opens an exciting new potential for electric vehicles and for the owners of electric vehicle fleets. Beyond the benefits to the electrical grid and the improved management of electricity resources, vehicle owners have the ability to earn money by selling power back into the grid. In theory, vehicle to grid technology could reduce the overall lifetime costs of an electric vehicle. This would make the adoption of electric vehicles more attractive and further increase the market share of these types of vehicles.

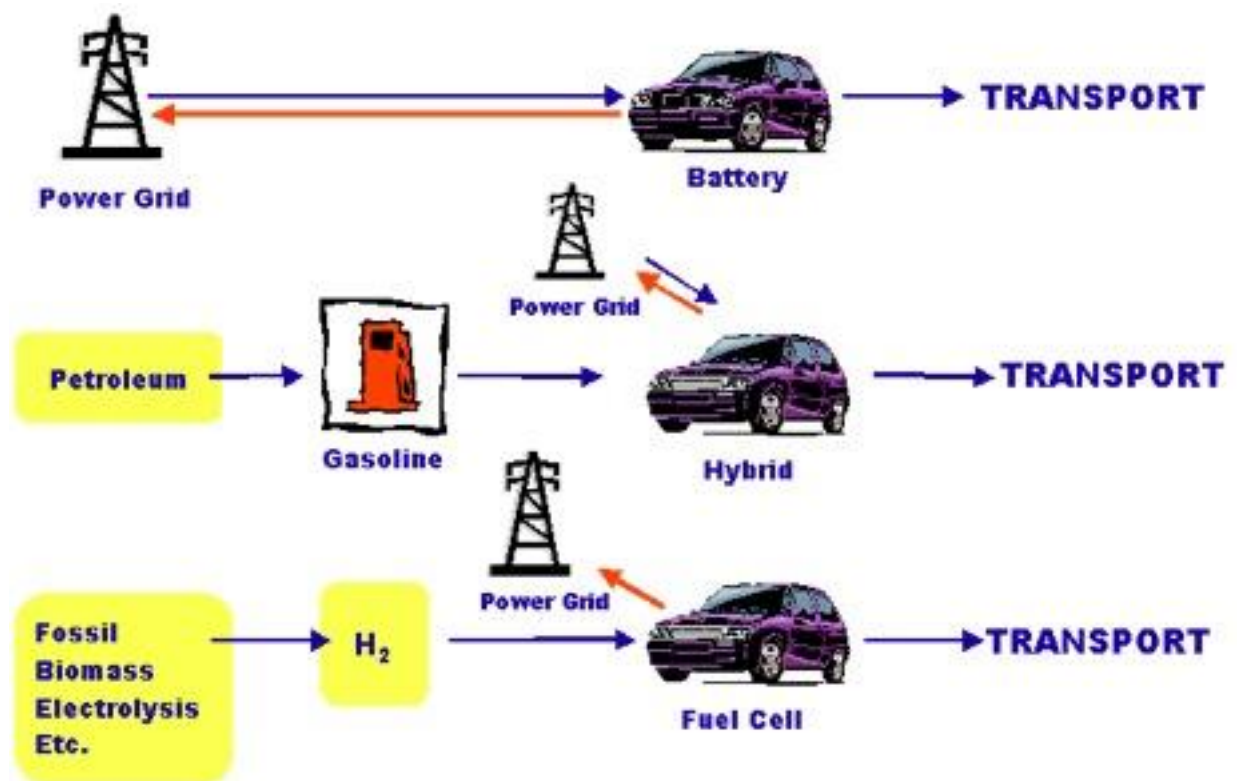


Figure 9 - BEV, PHEV, and FCEV Schematics for V2G [7]

On average, vehicles in the United States are only travelling on the road for approximately 4-5% of the day. Therefore, at least 90% of vehicles will sit unused, even during hours of peak traffic. We can infer that the size of a potential vehicle to grid resource could be huge. Consider that if a 15-kilowatt battery was placed in each of the 191 million vehicles in the United States, we would introduce 2865 gigawatts of electricity capacity.

To summarize, this technology is quite exciting as it offers huge benefits to both the transportation industry and electric power systems. We are starting to see federal government support into research on this concept as it can lead to a transition off petroleum and onto other sources of energy. This will be an exciting and bustling area of research over the upcoming years and beyond [8].

## **2.8. Electric Vehicle Regulations**

This section of the report will examine the major barriers to adoption of electric vehicles worldwide and give an overview of governmental public policy implemented or to be implemented to overcome these obstacles. This will focus on three major areas: charging networks, demand increases, and introduction of electric vehicles into programs of sustainable mobility.

### **2.8.1. Charging Networks**

Currently, the lack of wide spread charging infrastructure (especially on a national or even continental level) is one of the biggest challenges with the adoption of electric vehicle technology. Beyond just the accessibility of chargers for drivers, there are two further challenges from a usability standpoint, namely: spreading information to consumers on where charging stations are located relative to their location, and standardization of charging ports (see Section 4.6 – Charging Infrastructure for Electric Vehicles for more information on this).

The biggest challenge with charging networks is, of course, cost. Tariffs have been considered on the electricity provided by charging stations to help recoup the cost, however this would encourage users to simply charge at home and therefore become an impractical solution. Currently, there is not an agreement in place between government and industry on who should be responsible for covering these up-front investment costs. However, it is clear that government at both federal and municipal levels will have a large role to play in the investment into charging infrastructure [9].

As an example of how to tackle these issues, we look towards two major regulations imposed by the government of Catalonia. First, they provide a line of credit towards the owners of electric vehicles to use for private charging point installation. Second, they promote charging point installation in new buildings, especially public housing developments. For public networks, they offer subsidies reaching 30% of the total investment (up to a maximum of 600,00 euros). Additionally, they are working to create agreements with parking lot operators so that 1.5% of lots will have charging points [9].

### **2.8.2. Creating Electric Vehicle Demand**

Although it has been shown that electric vehicles can create environmental and economic benefits for their users over the lifecycle of the vehicle, consumers are heavily influenced by initial costs. This does not bode well for electric vehicles, which continue to be more expensive than traditional vehicles by about 20 to 30 percent on average. It can be concluded, therefore, that public subsidies are required to stimulate demand in this area.

This can be done in a number of ways. France has offered a 7000 euro grant for the purchase of electric vehicles, and Denmark and Israel have adopted similar measures. Another approach is to raise pollution standards on conventional internal combustion vehicles. Furthermore, raising taxes on gasoline or reducing taxes on electricity could also increase the economic attractiveness of electric vehicles. A final option to consider is the promotion of the usage of electric vehicle fleets [9].

### **2.8.3. Sustainable Mobility Programs**

The government of Catalonia has introduced proposals for a number of measures to introduce electric vehicles within sustainable mobility programs. Some of the specific measures are:

- Reduce the time and cost of travel. This can be accomplished by allowing electric vehicles access to high occupancy vehicle (HOV) lanes. Another way is to reduce the road tolls paid for by electric vehicle owners.
- Create “Park & Ride” sites. Such facilities, located at city outskirts, allow the electric vehicle owners to leave cars charging while they are at work.
- Creating agreements with private companies for the installation of charging stations in their car parks.
- The creation of an information system for electric vehicle owners to help identify the closest charging points, and the introduction of clear signage in these areas [9].



## 2.9. Environmental Impact of Electric Vehicles

While electric vehicles have the benefit of zero local emissions (exhaust) there is of course an environmental impact over the entire life cycle of the vehicle. It is not enough to assume that the simple adoption of electrical vehicles automatically guarantees a mitigation of climate change issues when compared to traditional internal combustion vehicles. Life cycle analysis shows a variety of key areas to examine when considering the overall environmental impact of electric vehicles.

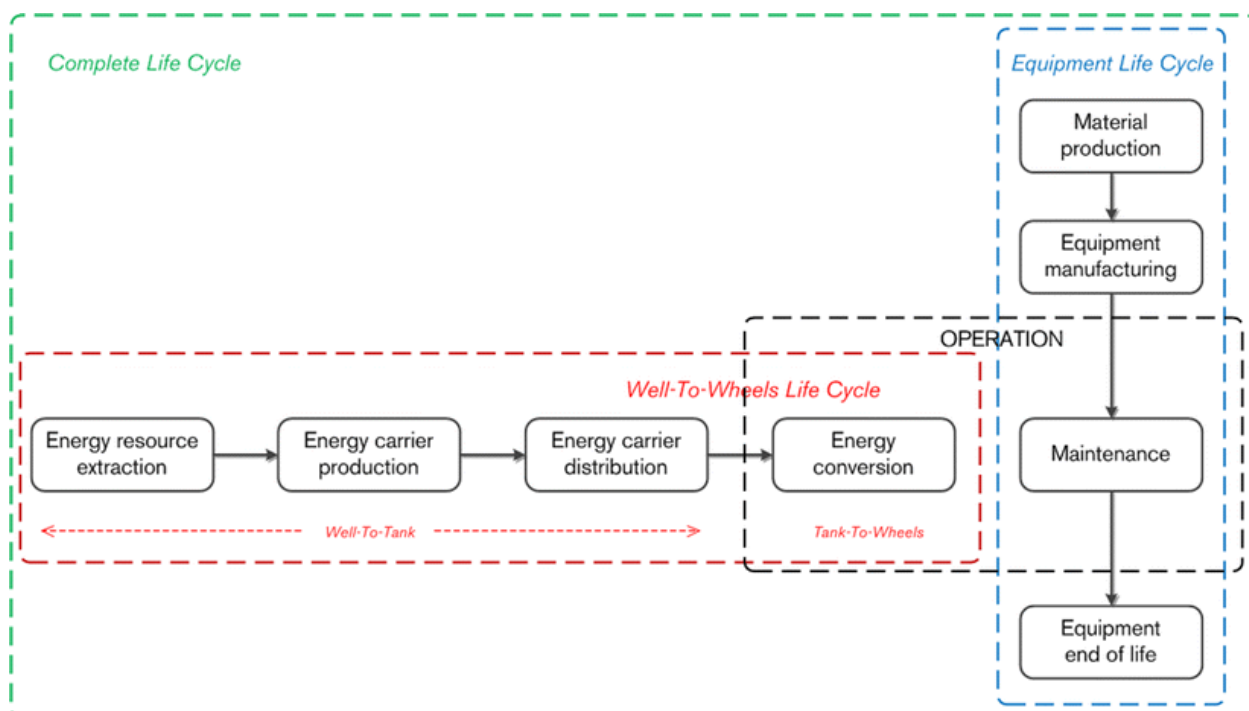


Figure 10 - Life Cycle of Electric Vehicles [10]

Studies have shown that generally, greenhouse gas emissions decrease as the electrification of the vehicle powertrain increases. However, it is extremely important to note that this improvement is highly dependent on the overall fossil fuel content of the electricity mix used for vehicle charging. We can expect that if electricity production becomes fossil fuel free on a globalized scale then electric vehicles will reach a full potential of climate change mitigation. It is key for researchers, policy makers, consumers, the automotive industry, and the electricity grid providers to recognize that the environmental benefits of electric vehicles are heavily tied to the overall energy system [10].

Furthermore, studies have shown that driving behaviour and traffic situations are important



factors when determining the environmental impact of electric vehicles. Benefits from electrical vehicles are best obtained in urban traffic, where low speed and frequent stops and starts are expected. Additionally, life cycle analysis shows the increased importance of the manufacturing stage, and how heavily the lifetime driving distance affects the overall environmental impact. Batteries are another critical area, as the mining required for battery manufacturing can have significant environment impacts. Batteries tend to age over time regardless of use, so heavily utilized electric vehicles are more beneficial [10].

## 2.10. Modelling of Electric Vehicle Demand

Determining the electric vehicle charging demand through modelling is an important area of current research. By determining total electric vehicle charging demand, we can make important inferences on the impact to the power distribution networks in a given location. Many aspects need to be considered including social, technical, and economic variables. Examples of these variables include place of residence for social, electric vehicle model for technical, and Gross Domestic Product (GDP) for economic. One method of probabilistic agent-based modelling uses all these variables simultaneously with the goal to obtain more realistic and precise results. Using this methodology, the total electric vehicle charging demand can be determined, which can then be utilized to analyse the impact on power distribution networks. We can see in Figure 10 below how these variables interact, along with other mobility parameters such as distance, day of week, etc. [11]

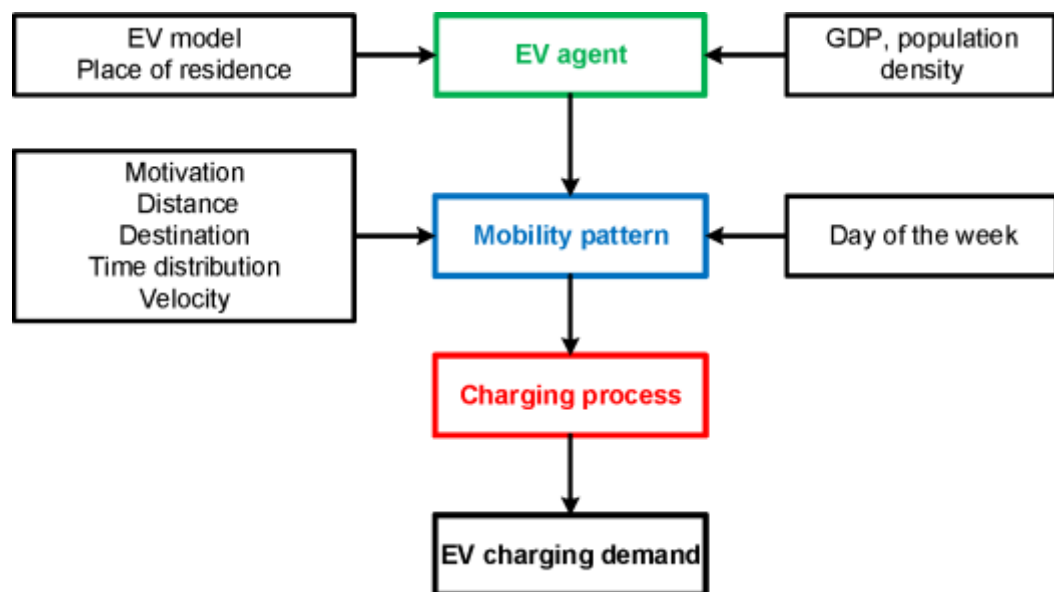


Figure 11 - Electric Vehicle Charging Parameters [11]

We will continue with a brief discussion of the different parameters necessary for the model. They can be clustered into three main groups: the EV agent, the mobility pattern, and the charging process.

### 2.10.1. EV Agent

In this model, each EV agent represents a vehicle and driver. The attributes include the electric vehicle model, mobility needs, and charging preferences. Important behaviours to consider are trips taken, energy consumption corresponding to each trip, the total energy consumed for the electrical network to charge the battery, and the charging decision. EV agents have three states with corresponding variables: driving, waiting, and charging.

In addition to this, there are two other agents with an influence on EV agent behaviour. They are the electricity retailer agent, which is responsible for the electricity price at a given instant, and the EV aggregator agent, which controls the EV charges to reduce electricity price. Figure 11 shows the relationship between the agents and EV agent in the structure of the model [11].

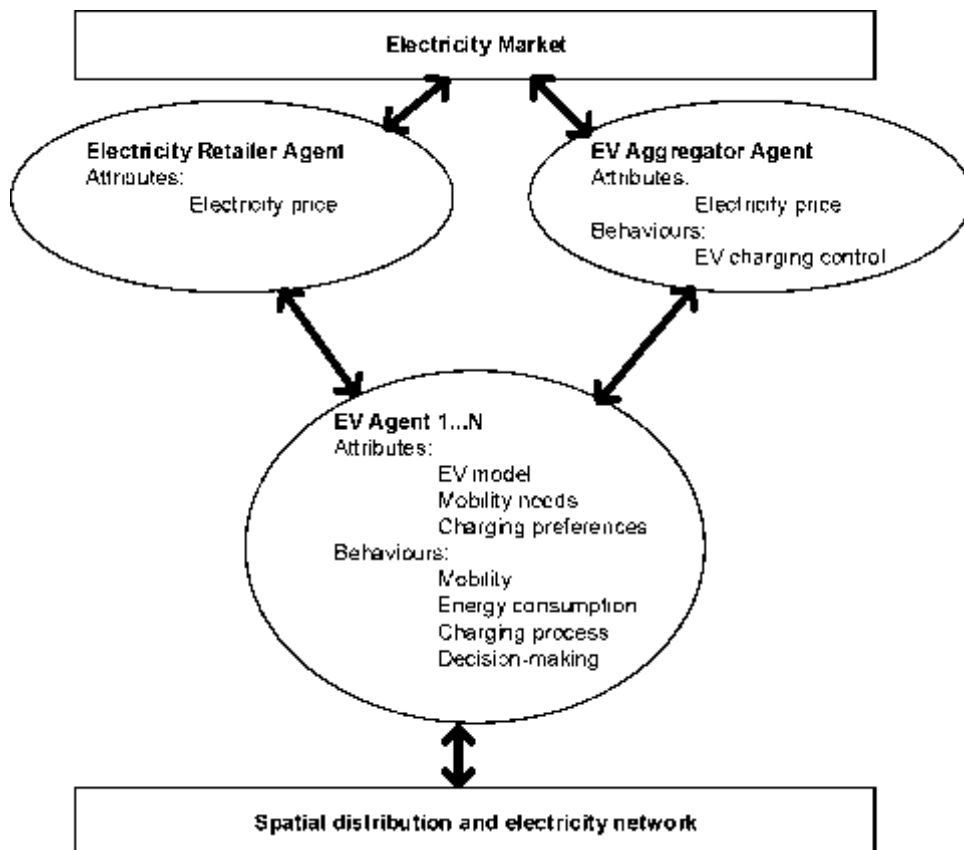


Figure 12 - Relationship Between EV Agents [11]

### 2.10.2. Mobility Pattern

Each EV agent has mobility variables assigned to it to model its mobility behaviour. The different mobility patterns are based on open data sources. The considered variables used to define the mobility pattern are defined as follows:

- Trips per day – The number of total trips is determined using a probabilistic variable. At least two trips should be assumed per day.
- Distance & Distance per trip – These variables are calculated using an exponential distribution function from public reports.
- Destination – In this model, the reason of displacement is used to determine the destination. These could be either personal issues or commuting.
- Day of the week & Time distribution – These parameters are used to determine when an electric vehicle consumes energy, as a function of the driver's motivation to travel on a given day.
- Velocity – In this situation, velocity is modelled as a constant value. The value is dependent on whether the trip is metropolitan or urban. For metropolitan cases, a value of 59.3 kilometres per hour is applied, and for urban cases a value of 22.2 kilometres per hour is applied.
- Initial time & Final time – A relationship between these variables can be found using average velocity and distance.
- Social variables – Certain social variables such as Gross Domestic Product (GDP) and population density are utilized to determine the total number of agents able to charge a vehicle at the same connection point [11].

### 2.10.3. Charging Process

For the purposes of this model, the charging process is assumed to be slow charging AC single-phase. It is dependent on variables that include EV model, battery capacity, state of charge, total energy needed to reach next destination, and time between trips. Furthermore, all electric vehicles are assumed to have Li-ion batteries. At the outset of the simulation all batteries are assumed to start fully charged. After that the state of charge depends on individual EV agent consumption [11].

## 2.11. Electric Vehicle Fleet Modelling

There are two approaches generally considered when modelling electric vehicle fleets. The first, an agent based approach with each vehicle and battery modelled separately, was discussed in a previous section. The second approach is known as the aggregate battery modelling approach. In this concept, the entire electric vehicle fleet is represented as a single lumped together battery. The method of modelling is well suited for applications related to complex energy planning studies. Furthermore, this approach is frequently utilized in hierarchical electric vehicle fleet charging management, which consists of two levels: the optimization of aggregate-level charging power profiles, and the distribution of the optimized profiles over the specific vehicles. In particular, this is useful for cases when an electric vehicle aggregator is present as an interface to electricity markets and power systems.

While this type of modelling has its benefits, there are also drawbacks to consider. One must consider that the battery capacity of the electric vehicle fleet will not remain constant, as at any given time a certain proportion of the vehicles will be in use. The following input time-distributions are required: the number of vehicles arriving to the fleet centre, the number of vehicles departing from the fleet centre, the number of vehicles connected to the grid, and the average state of charge of all the arriving vehicles [12].

## 2.12. Electric Vehicles in Barcelona

### 2.12.1. Mobility in Barcelona

Barcelona is aggressively pursuing electric mobility solutions as a method to reduce CO<sub>2</sub> emissions, reduce noise pollution, reduce oil dependency, improve efficiency, and to provide new opportunities for entrepreneurial, technical, and economic development and investment. A public-private platform was created called LIVE (Logistics for the Implementation of Electric Vehicles) and promoted by Barcelona City Council, with the object of:

- Supporting promotion and development of demonstration projects for electrical mobility (living labs).
- Providing resources and tools for the purpose of generating innovative attitudes in industry and economy, by promoting research and development.

- Proving support for the creation of local syndicates, national and European projects, and knowledge and technology programs from professional and university environments.
- Event and activity organization which work to implement electrical mobility in the Barcelona region.
- Promotion for the creation of recharge stations in private and public parking lots in Barcelona urban area [13].

### **2.12.2. Incentives**

Many incentives have been implemented on a national and municipal level to encourage the adoption of electric vehicles. These incentives include:

- National
  - Direct subsidies for purchase of electric vehicles
  - Modifications to registration tax
  - Free parking in controlled parking lots
  - Lower electricity tax
- Municipal
  - Up to 75% tax benefit for vehicle registration tax
  - Free recharging at all municipal points
  - Free parking in regulated areas of the city of Barcelona for residents with 100% electric vehicles
  - Public car parks with two percent of spaces allocated for electric vehicles and facilities ready for future inclusion [13]

These incentives will be looked at in depth in Section 3.2.

### **2.12.3. Electric Vehicle Fleets in Barcelona**

An overview of Barcelona's fleet strategy:

- The city of Barcelona has in excess of two hundred and eighty hybrid and plug-in electric vehicles in its fleet.
- At least fifty percent of the powered two wheeler (PTW) fleet in the city is expected to become electric.
- LIVE, discussed earlier, plans to work with distributors and manufacturers to create initial prototype units of electric vehicles for the Catalonia region.

- Transports Metropolitans de Barcelona (TMB) has an ongoing project collaboration with SIEMENS towards developing projects for the hybridization of minibuses and buses, as well as the implementation of 100 percent electrified routes in neighbourhoods with mobility issues.
- The city, along with help from a private consortium, is defining a car sharing system. Based on the “Mobility on Demand” concept developed for MIT in Boston, this is the first system of car sharing with electric vehicles. The new system improves on existing car sharing systems, as users are able to access vehicle on demand and return them where they see fit [13].

### **3. Benchmarking & State of Art of Electric Vehicle Fleets**

Vehicles fleets are an important part of a healthy and well-functioning city. They are required for public services such as transportation and policing, as well as for private businesses, such as package delivery services or taxis. Although a potential goal of dense urban cities would be to minimize vehicular traffic, in the short- to medium-term it is important to focus on how to transition our vehicle fleets to a form which is both more efficient and more sustainable for the environment.

Various aspects of cities can benefit from the introduction of electric vehicle fleets. In this section, we will examine a few major cases of the use of these types of fleets, and identify the major sectors in which they already operate. The case studies will focus mainly on Barcelona, but international examples will be considered as well. Following this we will examine the aid and incentives provided for the transition to electric vehicle fleets.

#### **3.1. Existing Sectors – Overview**

##### **3.1.1. Public Transportation**

One of the most prevalent examples of fleet electrification can be seen in public transportation, particularly buses. This is a phenomenon seen worldwide, in cities both large and small. In particular, the European Union has made efforts to promote this via the ZeEUS (Zero Emission Urban Bus System) project. The goal of the ZeEUS project is to test potential electric vehicle solutions through live operation, in order to more effectively roll out in future locations around Europe [14].

The ZeEUS project has four buses currently being tested in Barcelona. Initially two Irizar i2e 12m buses were rolled out in 2014. Most recently, the ZeEUS project has been responsible for the rollout of two new electric buses. These buses are 18m long articulating buses, manufactured by Solaris. The new buses are able to charge batteries while in use in specially built stations located in Zona Franca, and they are capable of both slow charging (done at the garage) or fast charging (done while in transit) [15].

Electric bus projects have also appeared outside of the EU. Notably, Chicago has introduced

a fleet of ten private buses, manufactured by Proterra. This is unique in the sense that this fleet is privately owned rather than publicly, making this America's first fully electric commercial bus fleet [16] [17].

### **3.1.2. Public Services**

Public services in cities is another prime opportunity for fleet electrification. This covers a wide variety of potential fleet operations, from emergency services to street cleaning. Using Spain as an example, garbage collection has already been electrified in both Madrid and Barcelona.

The electrification of these essential city services is important for not just pollution reduction but for noise reduction as well. In dense cities like Barcelona, many city services like garbage collection or street cleaning are often scheduled for late-night, off-peak hours. Reducing the noise pollution involved in the completion of these services is an important need for the general population of the city.

Urbaser, the company responsible for waste collection in Barcelona, utilizes Hybrys vehicles, which operate as hybrids. They are particularly suited for navigating the narrow streets in many of the city's neighbourhoods. The electric motor propels the truck when the speed is less than 20 km/h and gets power when the vehicle brakes or decelerates [18].

### **3.1.3. Taxis**

Spain has also seen an introduction of electric taxis in recent years, with these types of taxis appearing in cities such as Barcelona, Madrid, Zaragoza, Seville, Bilbao, Valladolid, Pamplona, Asturias, Granada, and Teruel. Although these taxis are still greatly outnumbered by traditional internal combustion engine taxis, they are gradually increasing in numbers across the country [19].

## **3.2. Transition to Electric Vehicle Fleets – Aid and Incentives**

One of the major reasons to convert an ICE fleet into an EV fleet is due to the economic incentives and financial savings. These can come in many forms, from simple energy savings to governmental benefits. We will discuss these each in detail in the following sections. In keeping with the scope of this thesis, we will focus on incentives in Barcelona and Spain in general. The first section will discuss financial assistance for the purchase of electric vehicles, then we will look at support specific to electric vehicle fleets. Following that we will look at cost



savings for electric vehicle owners, incentives for charging point installation, and finally municipal benefits in Barcelona.

### **3.2.1. Financial Assistance for Electric Vehicle Purchases**

Plan MOVEA is a system put in my place by the Spanish government to promote the purchase of electric vehicles. This system provides financial aid for any vehicle that runs using alternative energy, including electric, natural gas, or liquefied petroleum gas. Pedal assisted bicycles which use an electric motor are also included in this plan [20].

The Government of Catalunya has also issued a call for subsidies for the purchase of low emission vehicles for taxis, commercial use, or other services. The resolution states that the aim is to improve the quality of air in those municipalities where there is a high density of traffic. There is a specific time window in which the grant can be received [21].

Àrea Metropolitana de Barcelona (AMB) has introduced a subsidy for the purchase of electric bicycles. Up to 200 euros can be claimed for pedal assisted bicycles which use an electric motor. The subsidy can be acquired though the various stores in which the bicycles can be purchased [22].

Another system in place by the Spanish government to promote the purchase of electric vehicles a special exception from vehicle registration tax. This exception applies to vehicles with emissions of less than 120 g/km [23].

### **3.2.2. Support for Electric Vehicle Fleets**

The Spanish government has put a plan in place to encourage corporate investment in environmental protection. Under this plan, companies are able to deduct 8% of any investments made towards environmental improvements from their corporate tax. An investment made which reduces local emissions is eligible, so the use of more sustainable vehicles falls under this project [24].

Additionally, personal income tax deductions can be made for company vehicles. A deduction can be made of up to 30% in tax on earned income. This is for the granted use of vehicles that are considered energy efficient [22].

Project CLIMA (Carbon Fund for a Sustainable Economy) is another project put in place by the Spanish Government designed to reduce greenhouse gas emissions. Improvements to a

fleet resulting in an emissions reduction (e.g. purchasing electric vehicles) can be acquired using this fund [25].

Companies which utilize electric vehicle fleets may also be eligible for the 'Distintiu de garantia de qualitat ambiental' (Environmental Quality Guarantee). This is a Catalan eco-label designed to acknowledge products and services which surpass the legally required environmental quality criteria. This can further advertise your brand and set you apart from competitors, leading to an increase in business [26].

Finally, we will note that an increasing number of public tenders for fleets of vehicles or services in the mobility field include clauses with environmental stipulations concerning these fleets [22].

### **3.2.3. Cost Savings for Electric Vehicle Owners**

Within Catalonia, electric vehicles with the ecoviaT label have many cost saving benefits. Drivers can access to public toll roads from Monday to Friday free of charge. Furthermore, up to 30% discount can be received on stretches of motorway and tunnels for low emission vehicles with the ecoviaT label. Another benefit that can be utilized is the ability to drive on the HOV bus lane of the C-58 road [27].

Within Barcelona and some other municipalities, some public car park management companies have fitted charging points in parking spaces. Discounts are offered on the use of these charging points. Municipal roadside charging points are also offered for use with discounted or free use. Additionally, free or reduced parking is offered in many areas within the city. Some municipalities, Barcelona included, also offer discounts of up to 75% on yearly road tax [22].

### **3.2.4. Municipal Benefits in Barcelona**

The City of Barcelona has particular benefits for electric vehicle owners. To access these benefits, the vehicle owner must obtain an electric vehicle card from the city. One of the main benefits to cardholders is the ability to recharge vehicles at roadside stations in various locations in the city at no charge. Furthermore, cardholders are able to park in certain regulated city zones (green and blue spaces) without incurring a parking fee. These benefits lead to tangible economic benefits for fleet owners, such as reduction in parking and charging fees [28]. Finally, we note that a fleet electrification of 40% would result in reductions of 11% and 17% of the total NOx emissions in Barcelona and Madrid respectively [29].

## 4. Business Models for Future Fleet Electrification

Many existing vehicle fleets can benefit from a transition to electric vehicle fleets. We will now look at specific examples to examine the financial and environmental impact that this transition can have on both public and private fleets.

### 4.1. Taxis

In this section, we will consider a taxi driver upgrading his gasoline powered vehicle to an electric vehicle. The vehicle to be considered will be the BYD E6, the most common electric taxi in use in Barcelona [19]. This vehicle has a power consumption of 3.1 miles/kWh [30] and a cost of \$52,000 USD [31].

We summarize these characteristics in the following table:

BYD E6	
COST:	\$52,000 USD
FUEL ECONOMY:	3.1 miles/kWh

We will compare with a common gasoline based taxi used in Spain, the SEAT Toledo. This vehicle costs 18,180 EUR and has a fuel consumption of 4.8 L/100km and CO<sub>2</sub> emissions of 113 g/km [32].

We summarize these characteristics in the following table:

SEAT TOLEDO	
COST:	18,180 EUR
FUEL ECONOMY:	0.048 L/km
CO <sub>2</sub> EMISSIONS:	113 g CO <sub>2</sub> /km

A final important piece of information which will be used in this section is the average annual distance driven by a taxi. According to the 2014 Taxicab Fact Book, the average taxi drives 70,000 miles per year [33].

#### 4.1.1. Taxis in Barcelona

##### 4.1.1.1. Calculating Cost Savings

In Spain, the electricity price for an industrial consumer is 0.103 EUR/kWh [34]. We can calculate our energy costs on a per kilometre basis using the following formula:

$$1/3.1 \text{ kWh/mile} * 0.621 \text{ miles/km} * 0.103 \text{ EUR/kWh} = \underline{0.0206 \text{ EUR/km}}$$

Furthermore, in Spain, the gasoline price is 1.22 EUR/L [35]. We can calculate the fuel cost on a per kilometre basis using the following formula:

$$0.048 \text{ L/km} * 1.22 \text{ EUR/L} = \underline{0.0586 \text{ EUR/km}}$$

We can find the per kilometre savings of switching to an electric taxi by subtracting the previous results to reach a savings of: 0.0380 EUR/km

##### 4.1.1.2. Calculating Payback Period

Given an annual average driving distance of 70,000 miles/year, we can find the annual fuel savings using the following formula:

$$70,000 \text{ miles/year} * 1.609 \text{ km/miles} * 0.0380 \text{ EUR/km} = \underline{4,279.94 \text{ EUR/year}}$$

We can then calculate the payback period using the following formula:

$$52,000 \text{ USD} * 0.9 \text{ EUR/USD} / 4,279.94 \text{ EUR/year} = \underline{10.9 \text{ years}}$$

Note that this payback period does not consider the purchase of a new battery for the taxi, which may be required depending on the specified lifetime of the battery.

##### 4.1.1.3. Calculating Emission Reductions

Local emission reduction annually can be found using the following formula:

$$113 \text{ g CO}_2/\text{km} * 70,000 \text{ miles/year} * 1/609 \text{ km/miles} = \underline{12,727,190 \text{ g CO}_2/\text{year}}$$

Note that this transition to an electric taxi would increase the load on the grid, and therefore increase total emissions, based on the energy mix in Spain. We can calculate this increased load on the grid using the following formula:

$$1/3.1 \text{ kWh/mile} * 70,000 \text{ miles/year} = \underline{22,580 \text{ kWh/year}}$$

#### 4.1.2. Taxis in Stockholm

##### 4.1.2.1. Calculating Cost Savings

In Sweden, the electricity price for an industrial consumer is 0.066 EUR/kWh [34]. We can calculate our energy costs on a per kilometre basis using the following formula:

$$1/3.1 \text{ kWh/mile} * 0.621 \text{ miles/km} * 0.066 \text{ EUR/kWh} = \underline{0.0132 \text{ EUR/km}}$$

Furthermore, in Sweden, the gasoline price is 1.45 EUR/L [36]. We can calculate the fuel cost on a per kilometre basis using the following formula:

$$0.048 \text{ L/km} * 1.45 \text{ EUR/L} = \underline{0.0696 \text{ EUR/km}}$$

We can find the per kilometre savings of switching to an electric taxi by subtracting the previous results to reach a savings of: 0.0564 EUR/km

##### 4.1.2.2. Calculating Payback Period

Given an annual average driving distance of 70,000 miles/year, we can find the annual fuel savings using the following formula:

$$70,000 \text{ miles/year} * 1.609 \text{ km/miles} * 0.0564 \text{ EUR/km} = \underline{6,352.33 \text{ EUR/year}}$$

We can then calculate the payback period using the following formula:

$$52,000 \text{ USD} * 0.9 \text{ EUR/USD} / 6,352.33 \text{ EUR/year} = \underline{7.37 \text{ years}}$$

Note that this payback period does not consider the purchase of a new battery for the taxi, which may be required depending on the specified lifetime of the battery.

##### 4.1.2.3. Calculating Emission Reductions

Local emission reduction annually can be found using the following formula:

$$113 \text{ g CO}_2/\text{km} * 70,000 \text{ miles/year} * 1/609 \text{ km/miles} = \underline{12,727,190 \text{ g CO}_2/\text{year}}$$

Note that this transition to an electric taxi would increase the load on the grid, and therefore increase total emissions, based on the energy mix in Sweden. We can calculate this increased

load on the grid using the following formula:

$$1/3.1 \text{ kWh/mile} * 70,000 \text{ miles/year} = \underline{22,580 \text{ kWh/year}}$$

#### 4.1.3. Summary of Results

	BARCELONA	STOCKHOLM
<b>ELECTRICITY PRICE</b>	0.103 EUR/kWh	0.066 EUR/kWh
<b>ENERGY COSTS PER KM</b>	0.0206 EUR/km	0.0132 EUR/km
<b>GASOLINE PRICE</b>	1.22 EUR/L	1.45 EUR/L
<b>FUEL COSTS PER KM</b>	0.0586 EUR/km	0.0696 EUR/km
<b>TOTAL SAVINGS PER KM</b>	0.0380 EUR/km	0.0564 EUR/km
<b>ANNUAL SAVINGS</b>	4,279.94 EUR/year	6,352.33 EUR/year
<b>PAYBACK PERIOD</b>	10.9 years	7.37 years
<b>LOCAL EMISSION REDUCTION</b>	12,727,190 g CO <sub>2</sub> /year	12,727,190 g CO <sub>2</sub> /year
<b>INCREASED GRID LOAD</b>	22,580 kWh/year	22,580 kWh/year

## 4.2. Public Buses

In this section, we consider the transition of a diesel bus fleet to an electric bus fleet. The bus considered will be the Proterra BE34 Bus. Thorough testing has shown that the average energy consumption of this bus during real use conditions is 2.15 kWh per mile. We also note that the purchase price of this bus is \$904,490 USD and it has a total capacity of 55 people [37].

We summarize these characteristics in the following table:

## PROTERRA BE34 BUS

COST:	\$904,490 USD
FUEL ECONOMY:	2.15 kWh/mile
CAPACITY:	55 people

We will use a common, comparable sized bus as our baseline. We will consider the MCI 102DL3 Bus. This bus operates on diesel with a fuel economy of 39 L per 100 km. It also has a capacity of 55 people and a price of approximately \$350,000 USD [38].

We summarize these characteristics in the following table:

## MCI 102DL3

COST:	\$350,000
FUEL ECONOMY:	0.39 L/km
CAPACITY:	55 people

#### 4.2.1. Buses in Barcelona

##### 4.2.1.1. Calculating Cost Savings

In Spain, the electricity price for an industrial consumer is 0.103 EUR/kWh [34]. We can calculate our energy costs on a per kilometre basis using the following formula:

$$2.15 \text{ kWh/mile} * 0.621 \text{ miles/km} * 0.103 \text{ EUR/kWh} = \underline{0.138 \text{ EUR/km}}$$

Furthermore, in Spain, the price of diesel is 1.10 EUR/L [39]. We can calculate our fuel costs on a per kilometre basis using the following formula:

$$0.39 \text{ L/km} * 1.10 \text{ EUR/L} = \underline{0.429 \text{ EUR/km}}$$

We can find the per kilometre savings of switching to an electric bus by subtracting the previous results to reach a savings of: 0.291 EUR/km

#### 4.2.1.2. Calculating Payback Period

To calculate the payback period, we must first determine the total kilometres travelled annually by diesel buses in Barcelona. We will use the following statistics, obtained from TMB (Transports Metropolitans de Barcelona) [40]:

<b>Total number of buses</b>	1060
<b>Number of diesel buses</b>	528
<b>Maximum number of buses running (at rush hour)</b>	834
<b>Daily average speed</b>	12.08 km/hour

We assume that on average, one half of the maximum number of running buses are in operation:  $834 \times 0.5 = 417$  buses. We also assume that the number of these that are diesel operated is proportional to the totals:  $(528/1060) \times 417 = 208$  diesel buses running on average. Given the average speed of 12.08 km/hour, we can calculate:

$12.08 \text{ km/hour} \times 8760 \text{ hours/year} \times 208 \text{ diesel buses} = \underline{22,010,726 \text{ km travelled by diesel buses annually}}$

We can find the annual fuel cost savings using the following formula:

$22,010,726 \text{ km/year} \times 0.291 \text{ EUR/km} = \underline{6,405,121 \text{ EUR/year}}$

We can then calculate the payback period of upgrading the fleet using the following formula:

$\$904,490 \text{ USD} \times 528 \text{ buses} \times 0.9 \text{ EUR/USD} / 6,405,121 \text{ EUR/year} = \underline{67.1 \text{ years}}$

Note that this payback period does not consider the purchase of new batteries for the buses, which may be required depending on the specified lifetime of the battery.

#### 4.2.1.3. Calculating Emission Reductions

By removing the combustion of diesel, we essentially eliminate the production local emissions by these buses. Based on the fuel economy of the MCI diesel bus and the total number of kilometres travelled annually, we can determine the reduction in combusted diesel:

$22,010,726.4 \text{ km/year} \times 0.39 \text{ L/km} = \underline{8,584,183 \text{ L of diesel saved annually}}$



According to the EPA, one gallon of diesel emits 22.2 pounds of CO<sub>2</sub> [41]. We can calculate:

$$8,584,183 \text{ L} * 0.264172 \text{ gallon/L} * 22.2 \text{ pounds CO}_2/\text{gallon} * 0.453592 \text{ kilograms/pound} = \underline{22,835,163 \text{ kg of CO}_2 \text{ saved per year}}$$

Note that this transition to an electric bus fleet would increase the load on the grid, and therefore increase total emissions, based on the energy mix in Spain. We can calculate this increased load on the grid using the following formula:

$$2.15 \text{ kWh/mile} * 0.621 \text{ miles/km} * 22,010,726 \text{ km} = \underline{29,387,621 \text{ kWh/year}}$$

#### 4.2.2. Buses in Stockholm

##### 4.2.2.1. Calculating Cost Savings

In Sweden, the electricity price for an industrial consumer is 0.066 EUR/kWh [34]. We can calculate our energy costs on a per kilometre basis using the following formula:

$$2.15 \text{ kWh/mile} * 0.621 \text{ miles/km} * 0.066 \text{ EUR/kWh} = \underline{0.0881 \text{ EUR/km}}$$

Furthermore, in Sweden, the price of diesel is 1.42 EUR/L [42]. We can calculate our fuel costs on a per kilometre basis using the following formula:

$$0.39 \text{ L/km} * 1.42 \text{ EUR/L} = \underline{0.554 \text{ EUR/km}}$$

We can find the per kilometre savings of switching to an electric bus by subtracting the previous results to reach a savings of: 0.466 EUR/km

##### 4.2.2.2. Calculating Payback Period

To calculate the payback period, we must first determine the total kilometres travelled annually by diesel buses in Stockholm. We will use the following statistics, obtained from SL [43]:

<b>Total number of buses</b>	2,211
<b>Percent of buses consuming diesel</b>	16%
<b>Seat kilometres per year</b>	6,340,000,000 seat*km/year

Assuming an average bus capacity of 55 persons, we can estimate the total kilometres

travelled by diesel buses using the following calculation:

$$6,340,000,000 \text{ seat*km/year} / 55 \text{ seats} * 16\% \text{ diesel buses} = \underline{18,443,636 \text{ km travelled by diesel buses annually}}$$

We can find the annual fuel cost savings using the following formula:

$$18,443,636 \text{ km/year} * 0.466 \text{ EUR/km} = \underline{8,594,734 \text{ EUR/year}}$$

We can then calculate the payback period of upgrading the fleet using the following formula:

$$\$904,490 \text{ USD} * (2,211 * 0.16) \text{ buses} * 0.9 \text{ EUR/USD} / 8,594,734 \text{ EUR/year} = \underline{33.5 \text{ years}}$$

Note that this payback period does not consider the purchase of new batteries for the buses, which may be required depending on the specified lifetime of the battery.

#### 4.2.2.3. Calculating Emission Reductions

By removing the combustion of diesel, we essentially eliminate the production local emissions by these buses. Based on the fuel economy of the MCI diesel bus and the total number of kilometres travelled annually, we can determine the reduction in combusted diesel:

$$18,443,636 \text{ km/year} * 0.39 \text{ L/km} = \underline{7,193,018 \text{ L of diesel saved annually}}$$

According to the EPA, one gallon of diesel emits 22.2 pounds of CO<sub>2</sub> [41]. We can calculate:

$$7,193,018 \text{ L} * 0.264172 \text{ gallon/L} * 22.2 \text{ pounds CO}_2\text{/gallon} * 0.453592 \text{ kilograms/pound} = \underline{19,134,464 \text{ kg of CO}_2 \text{ saved per year}}$$

Note that this transition to an electric bus fleet would increase the load on the grid, and therefore increase total emissions, based on the energy mix in Sweden. We can calculate this increased load on the grid using the following formula:

$$2.15 \text{ kWh/mile} * 0.621 \text{ miles/km} * 18,443,636 \text{ km/year} = \underline{24,625,020 \text{ kWh/year}}$$

### 4.2.3. Summary of Results

	BARCELONA	STOCKHOLM
<b>ELECTRICITY PRICE</b>	0.103 EUR/kWh	0.066 EUR/kWh
<b>ENERGY COSTS PER KM</b>	0.138 EUR/km	0.0881 EUR/km
<b>GASOLINE PRICE</b>	1.22 EUR/L	1.45 EUR/L
<b>FUEL COSTS PER KM</b>	0.429 EUR/km	0.554 EUR/km
<b>TOTAL SAVINGS PER KM</b>	0.291 EUR/km	0.466 EUR/km
<b>ANNUAL SAVINGS</b>	6,405,121 EUR/year	8,594,734 EUR/year
<b>PAYBACK PERIOD</b>	67.1 years	33.5 years
<b>LOCAL EMISSION REDUCTION</b>	22,835,163 kg CO <sub>2</sub> /year	19,134,464 kg CO <sub>2</sub> /year
<b>INCREASED GRID LOAD</b>	29,387,621 kWh/year	24,625,020 kWh/year

### 4.3. Delivery Service

In this section, we will take up an example of a delivery service switching their fleet petrol scooters to electric scooters. We will consider Scutum brand scooters. Their website contains a built-in savings calculator with the following assumptions [44]:

	PETROL SCOOTER	ELECTRIC SCUTUM
<b>VEHICLE AMORTISATION TIME</b>	4 years	4 years
<b>CONSUMPTION (100 KM)</b>	4,0 litres	5,0 Kw/h
<b>SERVICES (5000 KM)</b>	55 €	45 €
<b>ENGINE OIL AND TRANSMISSION (5000 KM)</b>	45 €	0 €
<b>TYRES (15.000 KM)</b>	120 €	120 €

<b>BRAKES (10.000 KM)</b>	25 €	25 €
<b>AIR AND OIL FILTERS (5.000 KM)</b>	75 €	0 €
<b>SPARK PLUG (5.000 KM)</b>	15 €	0 €
<b>ANNUAL INSURANCE</b>	130 €	100 €
<b>ANNUAL CIRCULATION TAX</b>	20 €	8 €
<b>ANNUAL SCOOTER WASH</b>	20 €	10 €

The savings that are found range from 18.25 EUR for 4,000 km up to 3,744.25 EUR for 50,000 km.

#### 4.4. Discussion of Results

The results show the variety of effects, both economic and environmental, that occur from the transition from internal combustion fleets to electric vehicle fleets.

Economically, we can see that there is a large financial burden with is required to make this transition. Although there is a clear reduction in per kilometre energy/fuel costs, the payback periods are such that, at this time, it is not likely to be viable from a purely economic perspective.

It is worth noting what factors have the biggest influence on increasing the economic viability of the ICE fleet to EV fleet transition. First, due to the savings being accumulated on a per kilometre basis, the larger amount of distance covered on an annual basis helps to reduce the payback period.

Secondly, a large difference between electricity and fuel costs also reduces the payback period. This can be seen in the difference between Barcelona and Stockholm, where Stockholm has a much larger difference between these two costs.

From an environmental standpoint, there is a clear benefit to an ICE fleet to EV fleet transition. As shown with the public buses example, a huge amount of local CO<sub>2</sub> reduction can be achieved. Furthermore, we can expect a reduction of other pollutants as well, depending on the fuel type eliminated. It is, however, important to note that there will be an increase in

emissions based on the increased grid load, although these are not quantified in this thesis.

Although the environmental benefits are well established, due to the high economic load, it is more likely to see this transition accomplished by public entities, which have a focus on public good, than by private entities, which have a larger focus on economic returns. An aspect to be considered in future work is whether the increase in business due to consumer goodwill for adopters of EV vehicles can adequately outweigh the financial burdens.



## Conclusions

In conclusion, this report has identified the many effects of a transition towards electric vehicle fleets for businesses, both economic, environmental, and otherwise. Based on the results, we see a clear environmental benefit to the adoption of electric vehicle fleets, however, there is significant economic burden at this time. Ways in which this burden may be reduced over time include increasing the annual drive distance of vehicles, and a significant difference in cost between electricity and fuel prices. The latter could be achieved through taxation or tariffs, with the goal of encouraging EV fleet adoption. Further work on this topic should quantify the emissions due to increased grid loads.





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